Dissertação de Mestrado

Estratégias para a mitigação de herbivoria por capivaras (*Hydrochaeris hydrochaeris*) sobre reflorestamento de floresta ripária no alto rio das Velhas, Minas Gerais, Brasil

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Abstract:

This study investigated the potential of diversionary feeding and behavior contingent sonic deterrents in mitigating herbivory impacts by capybaras (*Hydrochaeris hydrochaeris*) in a riparian forest reclamation site in the Velhas river watershed, southeast Brazil. To this end, *Paspalum notatum*, popularly known as *batatais* or bahiagrass, was chosen as a diversionary food candidate and motion activated sonic alarms were used as deterrents. A field experiment compared plant cover and damage incidence between a control, from which capybaras were excluded by fencing, and open plots with and without sonic deterrents in which *P. notatum* was cultivated alongside other species of interest to the reclamation of the area. *P. notatum* proved distinctly preferred by capybaras, suffering 8.14 times more damages than the remaining species in its plots and suffering cover losses of up to 40% outside control plots while the remaining species showed no difference from the control. Sonic deterrents did not influence soil cover by any of the species, but did mitigate damage incidence on *P. notatum,* independently of time, whereas damages were 93% more prevalent in the plots without deterrents. This success was partial, however, as damage incidence in the presence of deterrents was still greater than in the control.

Keywords: diversionary food, sonic deterrent, *Paspalum notatum,* riparian forest reclamation, capybara, *Hydrochaeris hydrochaeris*

Resumo:

O presente trabalho investigou o potencial de recursos diversionários e dissuasivos sônicos em mitigar a herbivoria por capivaras (*Hydrochaeris hydrochaeris*) sobre plantios de recomposição de floresta ripária na bacia do rio das Velhas, MG. Para tal fim, a espécie *Paspalum notatum*, popularmente conhecida como grama de batatais, foi escolhida como candidata a recurso diversionário e alarmes disparados por movimento foram usados como dispositivos dissuasivos. Um experimento de campo comparou a ocupação do solo e a incidência de danos entre um controle, do qual capivaras foram excluídas por cercamento, e parcelas abertas com e sem alarmes em que *P. notatum* foi cultivada junto a outras espécies de interesse para a recuperação da área. *P. notatum* foi nitidamente preferida pelas capivaras, sofrendo 8,14 vezes mais danos do que as demais espécies em suas parcelas e apresentando uma ocupação de solo até 40% menor quando fora do controle, enquanto as demais espécies não diferiram do controle. Os alarmes não influenciaram a ocupação do solo por nenhuma espécie, mas mitigaram a incidência de danos sobre *P. notatum*, já que, independentemente do tempo, as parcelas sem alarmes sofreram 93% mais danos. Esse sucesso foi parcial, contudo, já que os danos ainda foram significativamente maiores nas parcelas com alarme do que no controle.

Palavras-chave: recurso diversionário, dissuasivo sônico, *Paspalum notatum*, recuperação de floresta ripária, capivara, *Hydrochearis hydrochearis*

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1. Introdução geral

Riparian forests provide cardinal ecosystems services such as biodiversity conservation (Nilsson 2007), regularization of hydrological cycles (Tabachi et al. 2000), water and soil conservation (Plamodon 1991, Alegre and Rao 1996) sediment retention (Welsch 1991, Sparovek 2002), carbon sequestration (Pires 2009), pollutant filtering (Lawrence et al. 1984, Liu 1997, Neill 2006) and streambank stabilization (Pollen 2007). A relevância da conservação e recuperação de bacias hidrográficas para os ecossistemas e populações humanas que delas dependem torna-se uma prioridade frente à intensa e extensa degradação ocorrida nas ultimas décadas. Intimamente integradas às bacias, matas ciliares provêm uma ampla gama de serviços ambientais como redução da erosão e do assoreamento (Welsch 1991, Sparovek 2002), estabilização das margens (Pollen 2007), filtragem de poluentes (Lawrence et al. 1984, Liu 1997, Neill 2006), conservação do solo e da água (Plamodon 1991, Alegre and Rao 1996), redução de enchentes (Tabachi et al. 2000), manutenção da biodiversidade (Nilsson 2007) e sequestro de carbono. Daí a emergência de iniciativas de recuperação de bacias hidrográficas e suas matas ciliares no Brasil e no mundo (Bullock 2011, Calmón 2011).

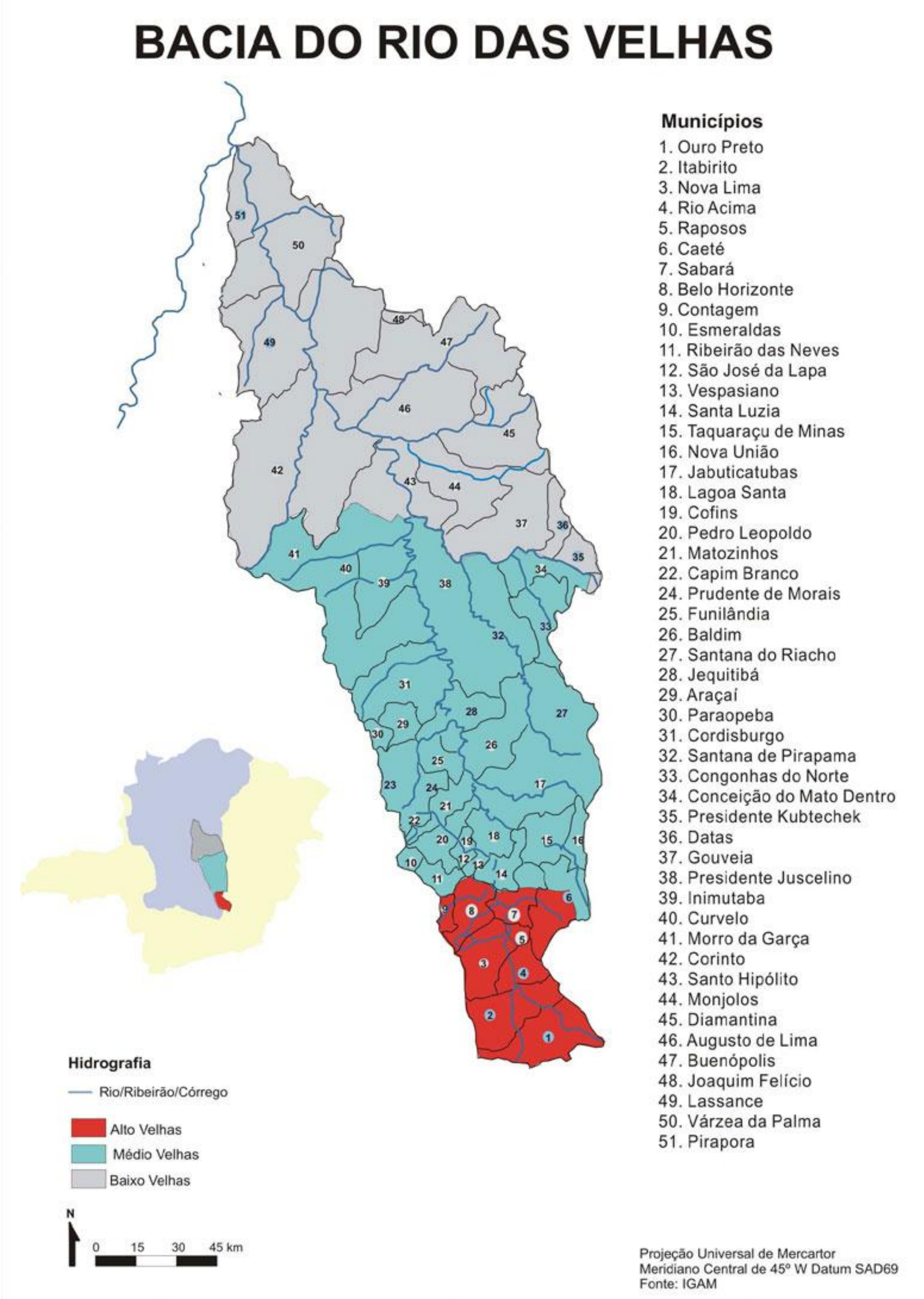
O sucesso de iniciativas de recuperação de floresta ripária depende da sobrevivência de suas plântulas lenhosas, o que gera uma demanda por medidas que reduzam a mortalidade das plântulas, protegendo-as inclusive de fatores bióticos como competição e herbivoria.

O presente trabalho busca explorar a viabilidade e eficácia de ferramentas de manejo de vida silvestre que aliviem a pressão predatória sobre plantios de recomposição de mata ciliar no contexto dos esforços de recuperação da Bacia do Rio das Velhas.

1.1. Caracterização da Bacia

A bacia do Rio das Velhas encontra-se na região central do estado de Minas Gerais, compreendida entre os paralelos 17º15’ S e 20º25’ S e os meridianos 43º25’ W e 44º50’ W. Sua área de drenagem de 29.173 Km², ou 5% da área do estado, perpassa 51 municípios (FEAM 2010) (Fig. 1) e abriga uma população de aproximadamente 4,3 milhões de habitantes (Camargos 2005). A nascente do Velhas encontra-se no Parque Municipal das Andorinhas, município de Ouro Preto, e o rio percorre 801 km até sua foz no Rio São Francisco no distrito de Barra do Guaicuy, município de Várzea da Palma (FEAM 2010). Seus divisores de água são a Serra do Espinhaço a Leste e as Serras do Ouro Branco, Moeda e Curral a Oeste (Moreira 2006). A bacia é subdividida em trechos alto, médio e baixo (Costa 2008) conforme a Fig. 1.

Fig. 1 - Localização da Bacia do Rio das Velhas em Minas Gerais, seus municípios de abrangência e subdivisões (Fonte CBH Velhas 2012)



A maioria dos cursos de água da bacia apresenta drenagem dendrítica e seus principais tributários são os rios Paraúna, Itabirito, Taquaraçu, Bicudo e

Ribeirão da Mata (Camargos 2005). São, ainda, dignas de nota as lagoas cársticas de tipo sumidouro que agem como reservatórios para os rios e podem ser encontradas em municípios como Lagoa Santa e Sete Lagoas (Pessoa 2005).

Segundo Camargos (2005), predominam na bacia o clima quente de inverno seco e o tropical de verão úmido. As precipitações anuais médias na tendem a diminuir da cabeceira para foz, indo de até 2.000 mm em Ouro Preto a 1.100 mm em Buenópolis e Várzea da Palma junto ao desague. As elevadas altitudes da região leste da média bacia permitem precipitações mais altas, chegando a 1.700 mm, principalmente na Serra do Espinhaço. Nos trechos médio e baixo, a estação seca dura três meses, de junho a agosto, mas o alto trecho apresenta secas mais longas, de 4 a 5 meses, indo de maio a setembro. Já as temperaturas anuais médias tendem a aumentar no sentido montante-jusante da calha principal, indo de 18ºc na cabeceira até 23ºc na foz.

Três biomas detentores de biodiversidade significativa ocorrem na bacia, o Cerrado, a Mata Atlântica e os Campos de Altitude. Entretanto, em 2005, usos antrópicos do solo ocupavam 48,6% da área total da bacia, enquanto a vegetação natural bem preservada, seja ela primária ou em estágio avançado de regeneração, correspondia a 32,9% e fragmentos em estágios mais iniciais de regeneração correspondiam a 14,4% da área (Camargos 2005) (Tabela 1).

Como a Tabela 1 mostra, o alto trecho da bacia concentra não apenas as aglomerações urbanas representadas principalmente pela RMBH como também as maiores áreas florestadas (Floresta Estacional Semidecidual e Ciliar), o que é explicado pela concentração de áreas protegidas nesse trecho, criadas principalmente para barrar a degradação e resguardar os mananciais hídricos que abastecem a RMBH (Camargos 2005).

Tabela 1 – Distribuição percentual dos biótopos na bacia do Velhas (Camargos 2005)

Biótopos	Alto		Médio		Baixo		Total	
	Km²	%	Km²	%	Km²	%	Km²	%
Campo	600	22,0	2.081	17,0	3.083	23,9	5.764	20,7
Capoeira	201	7,3	2.059	16,8	1.739	13,5	3.998	14,4
Mata	723	26,5	627	5,1	527	4,1	1.876	6,7
Cerrado	-	-	662	5,4	882	6,8	1.544	5,5
Reflorestamento	119	4,4	334	2,7	692	5,4	1.144	4,1
Usos Antrópicos	1.088	39,8	6.491	53,0	5.962	46,3	13.540	48,6
Total	2.730	100,0	12.253	100,0	12.884	100,0	27.867	100,0

A história da degradação ambiental da bacia está intimamente relacionada à sua ocupação e às atividades econômicas nela desenvolvidas. A colonização teve início no final do Século XVII, na esteira de bandeirantes que usavam o trajeto do rio como rota para explorar o interior do país em busca de ouro e gemas preciosas (Camargos 2005).

Findado o ciclo do ouro, pecuária e agricultura expandiram a degradação, principalmente pela conversão de áreas florestadas em pasto e lavoura. Posteriormente, já no fim do século XIX, a fundação da capital, Belo Horizonte, fomentou o adensamento populacional que culminaria na RMBH que hoje concentra 70% da população da bacia em seus 13 municípios por ela abrangidos (FEAM 2010). O descobrimento de jazidas de minério de ferro na bacia desencadeou um novo ciclo de exploração minerária e estimulou a instalação de siderúrgicas às margens dos cursos da bacia (Camargos 2005).

Atualmente, a perda de cobertura vegetal na bacia do Velhas é um problema grave e persistente. Entre Julho de 2009 e Agosto de 2011, 6.705,89 hectares de mata nativa foram suprimidos na bacia do Velhas (IEF 2012). O desmatamento está concentrado nas bacias média e baixa, áreas menos urbanizadas, em que predomina a atividade pecuária e há menos áreas protegidas, essas concentradas no alto rio das velhas de modo a resguardar o abastecimento de água da RMBH (Camargos 2005).

Já a degradação da qualidade da água empobrece as comunidades aquáticas e ameaça a saúde humana. A situação é tão crítica que no 3º semestre de 2012, todos os corpos de água da bacia apresentaram alguma violação de parâmetro em relação ao limite legal de sua classe de uso, incluindo aí coliformes termotolerantes, demanda bioquímica de oxigênio e níveis de fósforo, manganês e arsênio (IGAM 2012). As principais fontes de contaminação são o despejo de esgoto doméstico e industrial, o beneficiamento de ouro e ferro e a atividade siderúrgica. Os cursos de água menos contaminados concentram-se à margem direita do rio, associados ao complexo do espinhaço, enquanto os mais contaminados passam pela RMBH (IGAM 2012).

Nos últimos 15 anos, esforços de recuperação ambiental significativos vêm sendo empreendidos na bacia por órgãos do Sistema Estadual do Meio Ambiente em parceria com a sociedade civil organizada e a Universidade Federal de Minas Gerais (UFMG). O Projeto Manuelzão, programa de extensão da UFMG, lançou em 2003 a meta de reabilitar a bacia de modo a permitir nado, pesca e navegação no rio das Velhas até 2010. Em 2004 a meta foi assumida pelo governo estadual e em 2007 incluída em um grupo prioritário de 57 projetos estruturais. Os objetivos da Meta não puderam ser concretizados até 2010, mas o sucesso do programa pode ser comprovado pela ampliação do tratamento de esgoto coletado na bacia de 1,34% em 1999 para 76,03% em 2011 (FEAM 2010). Adicionalmente, as populações de peixes que em 2000 estavam confinadas a um trecho de 200 km da extensão do rio pela contaminação foram registradas ao longo de 580 km em 2010, retornando ao trecho médio (Polignano et al. 2012). No intuito de continuar os esforços de recuperação da bacia, lançou-se, ainda em 2010, a Meta 2014 que reitera o objetivo de recuperar a bacia até que se possa nadar, pescar e navegar ao longo de todo o rio das Velhas.

2. Introduction

Riparian forests provide cardinal ecosystems services such as biodiversity conservation (Nilsson 2007), regularization of hydrological cycles (Tabachi et al. 2000), water and soil conservation (Plamodon 1991, Alegre and Rao 1996) sediment retention (Welsch 1991, Sparovek 2002), carbon sequestration (Pires 2009), pollutant filtering (Lawrence et al. 1984, Liu 1997, Neill 2006) and streambank stabilization (Pollen 2007). Hence, riparian reforestation has been taken up as part of watershed reclamation efforts in various parts of Brazil and the world (Bullock 2011, Calmón 2011). Since seedling survival is essential to the success of riparian forest reclamation, it is important to protect seedlings from abiotic and biotic pressures, including herbivory damages, especially in the first months after transplantation. Indeed, herbivore exclusion has increased riparian forest reclamation success (Sweeney et al. 2002).

Hydrochaeris hydrochaeris or capybaras, as they are popularly known, occur in the tropical Americas from Panama to Northern Argentina. Their habitat requirements include forested patches for shelter and parturition, permanent water bodies for feeding, copulation and predator evasion, and grazing areas for feeding (Ojasti and Sosa Burgos 1985, Alho et al., 1989, Herrera and MacDonald, 1989). Despite anecdotal reports of damages caused by capybara grazing to crops and riparian reforestation stands being relatively common, damage assessments remain rare. Nevertheless, damages have been reported for corn, rice and sugarcane crops (Mendes 2003, Ferraz 2003) with damage incidence reaching as much as 25% of corn fields (Ferraz 2003). Capybara damage is closely associated with proximity to water bodies and forested areas, sharply decreasing with distance from them (Ferraz 2003). This puts riparian forested areas in early successional stages at a particular risk to grazing impacts, demanding management practices for damage control. Buried fences efficiently exclude capybaras from reforestation sites, but their implantation is very expensive and not always possible as slope steepness hampers installation and flooding can rip the fence off the ground. Therefore, complementary management tools must be developed for damage mitigation.

Seen as unlike invasive species, native species perform ecological roles, sometimes key ones, in their ecosystems of origin (Delibes-Mateos 2011) and considering ethical, legal, and public opinion constraints on lethal suppression, management practices for native species should strive for non-lethality. This study explores the viability of diversionary feeding and behavior-contingent deterrent devices to mitigate capybara grazing damage. Experiments were conducted in an actual riparian reforestation site at early successional stage, enabling assessment of management practices in a real operational situation, albeit a small scale one.

Diversionary feeding is a management practice that involves supplying food to problem animals to divert them away from resources or areas targeted for protection. It does not rely on population suppression (Sullivan and Sullivan 2008) and might, in fact, lead to population increases depending on duration, food supply volume and target species (Taitt 1981, Taitt and Krebs 1981). It has been successfully employed to control damages to crops and young forest stands at early stages of succession by rodents such as rabbits, squirrels and voles as well as other mammals, such as boars (Calenge et al. 2004, Sullivan 1992, Sullivan and Klenner 1993, Sullivan and Sullivan 2008), but has also failed in satisfactorily reducing damages to young forest stands (Sullivan and Sullivan 2004). An important first step in determining its viability is establishing food preferences in the target species (Miller 2006).

Paspalum notatum (Poaceae), popularly known as *batatais* in Brazil or bahiagrass in English speaking countries, was selected as a diversionary food candidate because of its potential as a forage and as a pioneer in the early stages of riparian revegetation in the Brazilian context. It is a native species (Baki 92) and despite being an aggressive colonizer in open sunlight, it is readily replaced by other species once shaded (Döbereiner 1972). Its mutualistic association with *Azotobacter paspali* enables it so survive on poor soils and yields considerable nitrogen fixation of up to 93 kg/ha/year (Day et al. 1975). It has also been found to promote the development of arbuscular mychorriza networks and facilitate the infection of arboreal species (Ishii 2007). Other useful capacities include surface erosion control and slope stabilization (Lu 2001, Grace 2000), phytoremediation of soils with high aluminum concentrations (Huang 2009) or deactivated mining areas and tailing ponds contaminated by heavy metals such as Pb, Zn and Cd (Xia 2004; Shu et al. 2002). As a forage, *batatais* has good nutritive values, retained when mature

(Arthington et al., 2005), and has been shown to provide sufficient digestible energy and protein to breeding cattle (Hirata et al., 2003) despite its lower productivity when compared to other pasture grasses.

Because of their simplicity and immediate effects, electronic devices emitting aversive stimuli such as loud noises or bright lights are another interesting tool for non-lethal pest management, although animals will eventually habituate to the stimuli, limiting their usefulness (Koehler et al. 1990, Bomford and O'Brien 1990, Nolte 1999). One way to slow habituation down and prolong deterrence is to employ behavior-contingent devices that are activated by specific animal behaviors such as entering a specific area (Shivik and Martin 2000, Belant et al. 1996). Sonic devices of various natures have been shown effective to varying degrees, especially when short-term deterrence of pests is required for critical periods (Koehler et al. 1990, Belant et al. 1996, Gilsdorf et al. 2003), but have also failed utterly in repelling target species (Koehler et al. 1990, Roper and Hill 1986, Bomford 1990, Bellant 1998). Attempts to exclude established rodents from their residence areas with ultrasonic devices have proven particularly ineffective (Schumake 1995, Gilsdorf et al. 2003). The present study assessed the effectiveness of behavior-contingent deterrent devices in mitigating capybara damage to riparian reforestation stands in early successional stages.

This study was designed to test the hypotheses that 1) *P. notatum* will be preferred by capybaras over the remaining species available, thus shielding other species and 2) trampling and feeding damages by capybaras will be smaller in the presence of deterrent devices.

3. Materials and methods

3.1. Study Site

The study site is located in the outskirts of Belo Horizonte, in the State of Minas Gerais, Southeast Brazil, at the confluence point of the Velhas river and a minor tributary to the left margins of both (S19° 50' 30.102", 43° 52' 6.6714" W). The area had been previously disturbed by the removal of its riparian forest and its vegetative cover was thin and dominated by ruderal species. As part of the reclamation efforts undertaken in the Velhas watershed, the site was cleared and reforested with seedlings of an assortment of woody species appropriate to the reclamation of its riparian strip. Capybara presence was confirmed by detection of scat in the area and footprints in its vicinities, prior to and throughout the experiment.

Fig. 2 - Study site at confluence point of the Velhas River and minor tributary in the outskirts of Belo Horizonte, state of Minas Gerais, southeast Brazil (S19° 50' 30.102", 43° 52' 6.6714" W).

3.2. Cultivated Plant Species

P. notatum seeds were acquired commercially and inoculated with *Azotobacter paspali* (108 cells/ml), 500 ml/kg of seed at the Laboratory of Plant-Microorganism Interaction and Degraded Land Reclamation of the Federal University of Minas Gerais, Brazil. (LIMP/UFMG)

Helianthus annuus (Asteraceae), also acquired commercially, was selected for planting in the plots without *batatais* to reduce erosion. Its quick vertical growth and high seeding density also facilitated identification of trampling damages when compared to the woody species planted in the area.

Seedlings of an assortment of woody species selected for their value to riparian forest reclamation obtained from the LIMP were cultivated alongside the aforementioned herbaceous ones at 3 x 3 m spacing and received complete fertilization as follows: triple 217 superphosphate (500 kg ha 218 -1), KCL (382 kg ha-1), MgSO47H2O: 50 kg ha 219 -1, ZnSO47H2O: 46.8 kg ha 220 -1, Mo7O24H2O:1.76 kg ha-1, urea: 222 kg ha-1. As detailed in Annex 2, the following species were cultivated in the area: *Acrocomia aculeata, Acrocomia* *intumescens, Albizia hasslerii, Anaderanthera colubrina, Astronium fraxinifolium, Bixa orellana, Caesalpinia echinata, Capsella bursa-pastoris, Cariniana estrellensis, Cassia occidentalis, Cecropia pachystachya, Ceiba speciosa, Centrolobium tomentosum, Copaifera langsdorfii, Coussapoa microcarpa, Croton urucurana, Dypterix alata, Enterolobium contortisiliquum, Eriobothrya japônica, Erythrina falcata, Eugenia pyriformis, Eugenia uniflora, Hymenaea courbaril, Inga ingoides, Jacaranda cuspidifolia, Lithraea molleoides, Luehea divaricata, Luehea grandiflora, Macherium sp., Malpighia glabra, Miconia cinnamomifolia, Mimosa bimucronata, Mimosa caesalpineafolia, Morus nigra, Myrocarpus frondosus, Myrtus communis, Ocotea puberula, Persea, americana, Piptadenia gonoacantha, Platycyamus regnellii, Protium heptaphyllum, Psidium guajava, Psidium guianeense, Pterigota brasiliensis, Punica granatum, Rapanea guyanensis, Samanea tubulosa, Schizolobium parahyba, Swietenia macrophylla, Tabebuia chrysotricha, Tamarindus indica, Tibouchina granulosa* and *Trichilia apiana*.

Woody species were transplanted to the study site in late December 2011, while the herbaceous species were directly seeded in the area in early March 2012.

3.3. Experimental design

The experimental design employed was of completely randomized blocks with 6 treatments and 3 blocks. The control area (fenced plots) received two treatments in 3 contiguous blocks of 56 m² each, totaling 168 m², while the experimental area (unfenced plots) received 4 treatments in 3 contiguous blocks of 112 m² each totaling 336 m². The control and experimental areas were immediately adjacent to each other. The treatments were as follows:

Control area:

1 – Fenced plots with *P. notatum*

2 – Fenced plots with *H. annuus*

Experimental area:

1 – Unfenced plots with *P. notatum* and deterrent devices

2 – Unfenced plots with *H. annuus* and deterrent devices

3 – Unfenced plots with *P. notatum*

4 – Unfenced plots with *H. annuus*

P. notatum invaded *H. annuus* plots early on the cultivation, colonizing small areas within them. All land access to the study site area was fenced, so it could only be reached from the rivers. All fences reached 20 cm deep, so capybaras could not dig below them.

3.4. Deterrent devices

The deterrent devices employed in this study were Key West DNI 6000 motion–activated sonic alarms of 105 dB of power and a sensory range of 8 m of length and 4 m of width. In early May 2012, two such sensors were installed in each of the 28 m² plots that received them, positioned so as to maximize the area covered by the sensors within the plot and avoid detection outside of it.

3.5. Sampling

Soil occupation by *P. notatum*, *H. annuus* and all other species, including cultivated seedlings and spontaneously occurring herbs grouped under the umbrella tag of *native species,* was estimated with the use of a one m² square subdivided in 100 identical cells (Toledo and Schultze-Kraft, 1982). Three such samples were collected per plot over 10 sampling events, beginning in early May 2012 and ending in early September 2012. Trampling and feeding damages were visually identified and the ratio of cover damaged for each species in a given sample was obtained from the area occupied by a species and its impacted subarea. Sampling began in earl may 2012

3.6 Statistical analysis

The effects of time and the treatments on plant cover were determined by quasi-likelihood regression analysis, wherein the link function and variance were determined by the LOWESS method (Locally Weighted Scatterplot Smoothing). This same methodology was used to determine whether the effect of time on native species cover varied because of its association with either *P. notatum* or *H. annuus,* while correlations between native species and *P. notatum* or *H. annuus* covers was verified by Spearman correlation. The need to consider interactions between treatments and time, that is, to assess whether differences between treatments varied over time, was determined by the F test. To assess the effects of treatment on the ratios of plant cover damaged by capybaras, the Mann-Whitney test was used to compare the two unfenced treatments, while the control groups were compared to the unfenced treatments by the Wilcoxon signed-rank test, so as to avoid distortions by the high number of zeroes in the control groups. The *P. notatum* and native species respective ratios of herbivory damage were compared by the Kruskal-Wallis test as was the effect of time on the damaged ratios. Analyses were conducted on software *R* version 2.15.0. Significance level was set to 5% for all of them.

4. Results

4.1. Plant cover

4.1.1. *P. notatum*

Figs. 3 illustrates *P. notatum* soil occupation averages (%) and variance for each treatment over time (days), apparent differences between control and treatments can be seen on days 10, 17, 24 and 76. Influence of time was verified for both treatments and control ($p<0.001$) and the cover receded 2.2% per day on average (Table 2). Plant cover differed significantly over time between control and treatments ($p=0.041$), whereas cover was 30% smaller in the presence of devices and 40% smaller in their absence (Table 2). No significant difference was found between the treatments with and without deterrents ($p=0.381$). Average differences between treatments did not vary over time ($p=0.073$).

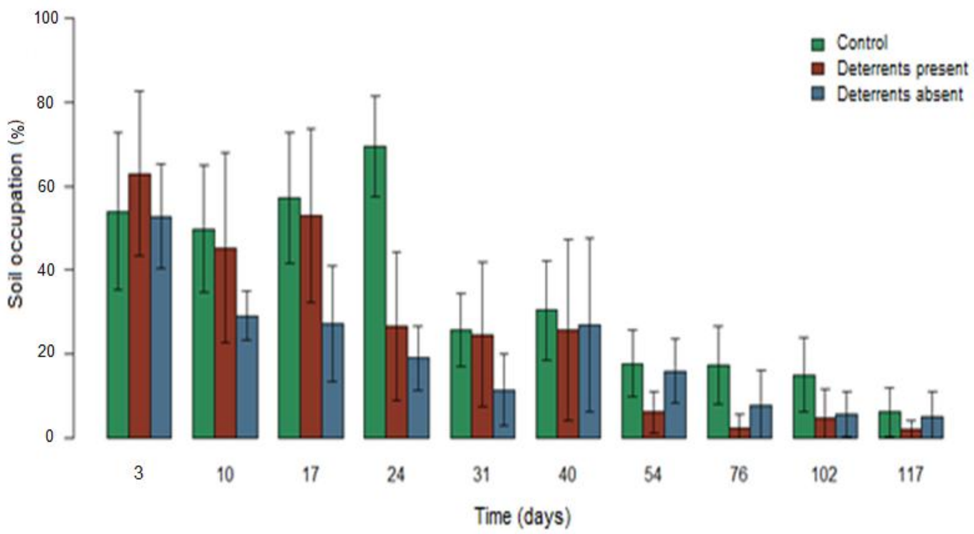


Fig. 3 – Descriptive measures of *Paspalum notatum* cover averages (%) and variances over time (days)

4.1.2. *H. annuus*

Fig 4 illustrates *H. annuus* soil occupation averages for each treatment over time (days). Table 3 shows time also influenced the *H. annuus* cover ($p<0.001$), which receded 5.4% per day on average until disappearing after the 54th day. No significant differences were found between any of the treatments. Average differences between treatments did not vary over time ($p=0.593$).

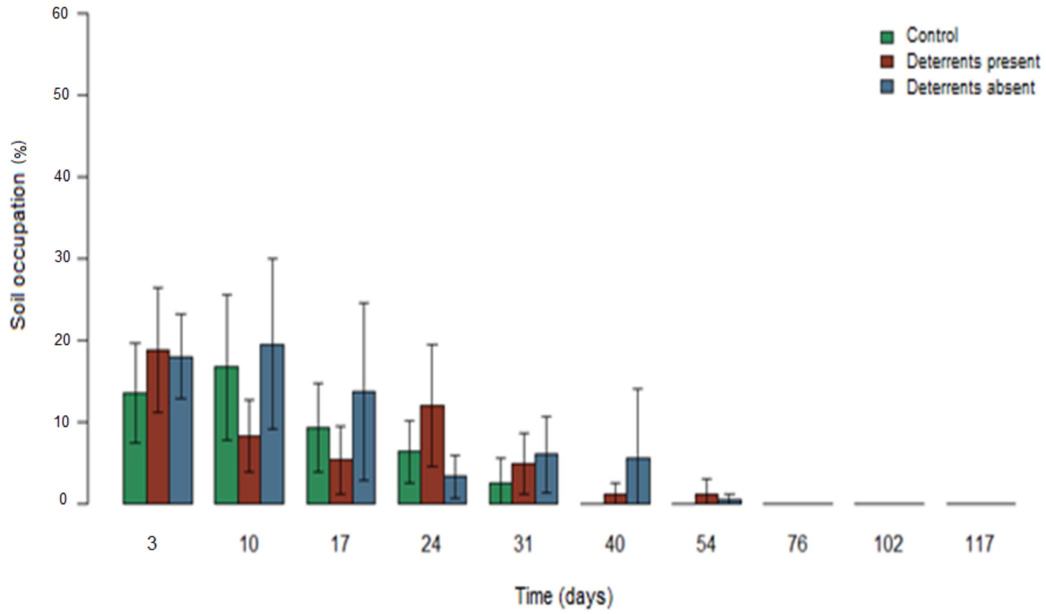


Fig. 4 – Descriptive measures of *Helianthus annuus* cover averages (%) and variances over time (days)

4.1.3. Native species

Fig. 5 illustrates soil occupation averages for each treatment over time (days). Table 4 shows time influenced native plant cover significantly ($p<0.001$), producing an average increase of 0.5% per day. No differences were found between any of the treatments. Average differences between treatments did not vary over time ($p=0.855$).

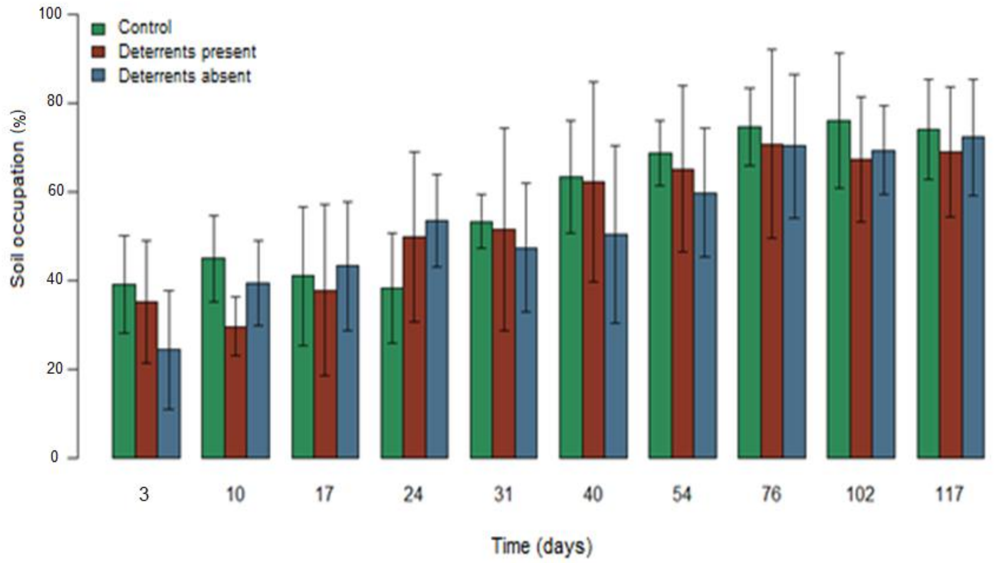


Fig. 5 – Descriptive measures of native species cover averages (%) and variances over time (days)

4.2. Effects of association with *P. notatum* or *H. annuus* on native species cover

Native cover was negatively correlated with both *batatais* and sunflower covers ($p<0.0001$) (Table 5). Fig. 6 shows that native species cover was initially greater alongside the cultivation of *batatais* than of sunflower, a behavior which reversed after the 68th day. Native species cover expansion was influenced by its association with either *batatais* or sunflower ($p=0.006$), being faster alongside sunflowers ($\beta=0.007$) than *batatais* ($\beta=0.003$) (Table 6).

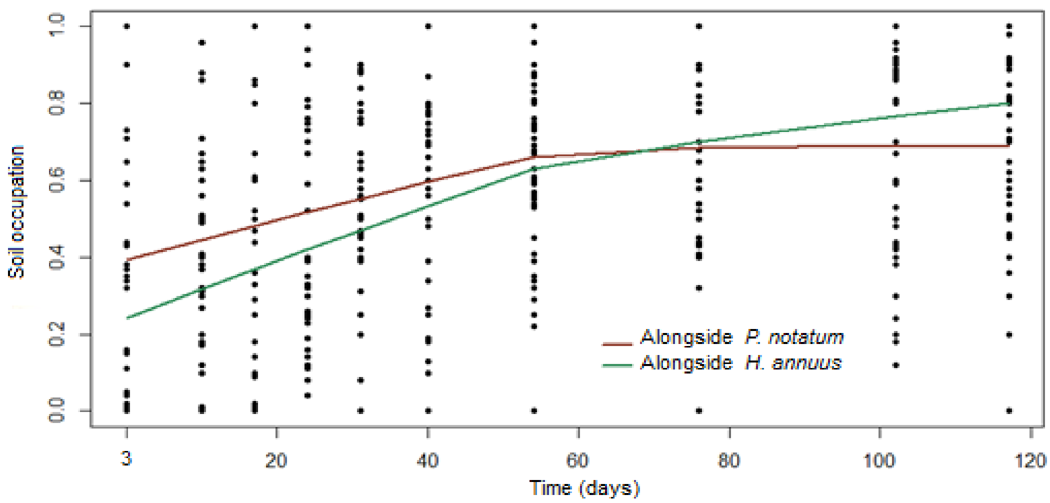


Fig. 6 - Dispersal diagram for native species cover alongside *Paspalum notatum* and *Helianthus annuus* over time (days) with curves adjusted by LOWESS method

4.3. Herbivory and trampling damages

4.3.1. *P. notatum*

Fig. 7 illustrates herbivory incidence averages over time (days). Table 7 shows time did not influence herbivory incidence (p=0.623), indicating the effects of time on plant cover decline were not caused by grazing, but seasonal. Fig. 8 illustrates damage incidence in the presence and absence of treatments, independently of time. Damages were 93% more prevalent in the absence of deterrents than in their presence (p=0.0005) and significantly more severe in both unfenced treatments than in the control group, which suffered no damage at all (p=0.001) (Table 8).

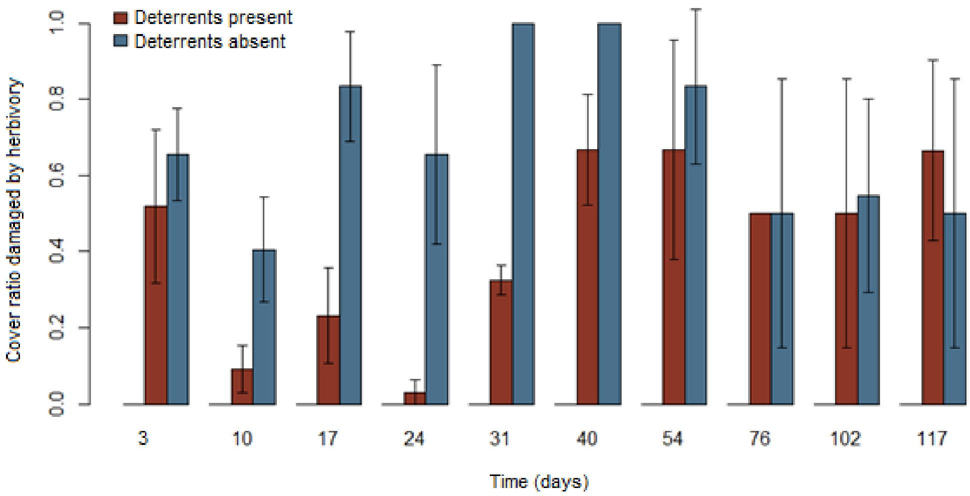


Fig. 7 – Averages ratios of *Paspalum notatum* cover damaged by herbivory over time (days)

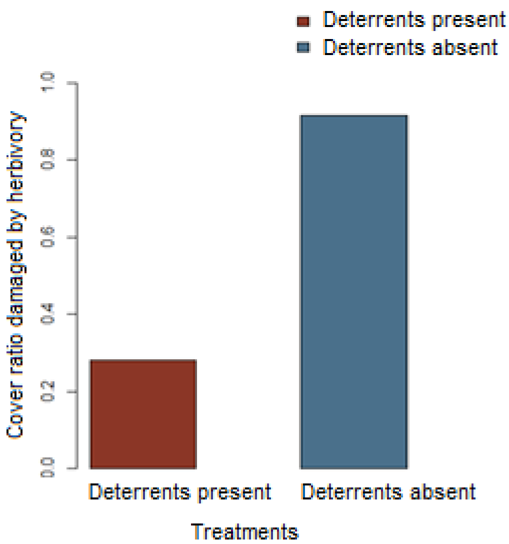


Fig. 8 – Ratio of *Paspalum notatum* cover damaged by herbivory independently of time.

4.3.2. *H. annuus*

Fig. 9 illustrates herbivory incidence averages over time (days). Table 9 shows no influence of time on herbivory incidence, independently of treatment, was found (p=0.518), indicating effects of time on plant cover decline were not caused by grazing, but seasonal. Figure 10 illustrates time independent damage incidence on *H. annuus*. No difference was found between treatments with and without deterrents (p=0.059), but only the treatment without deterrents differed from the control group, which suffered no damages (p=0.008) (Table 10).

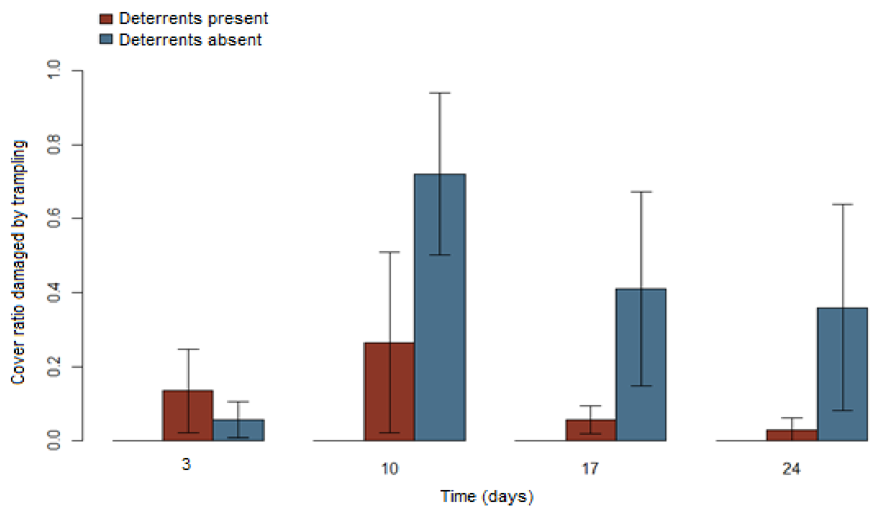


Fig. 9 – Average ratios and variances of *Helianthus annuus* cover damaged by trampling over time (days)

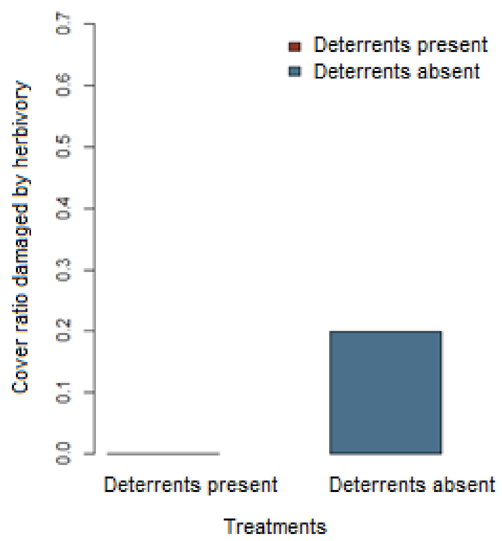


Fig. 10 – Ratio of *Helianthus annuus* cover damaged by trampling independently of time

4.3.3. Native species

No influence of time on the ratio of native species cover damaged by herbivory was found (p=0.577) (Table 11). Median values for all treatments at all times equaled zero, which made graphic representation impossible. Table 12 shows that independently of time, herbivory damage incidence for native plants did not differ between the treatments with or without deterrent devices (p=0.837). Damages in the control were null and significantly smaller than in both the presence of deterrents (p<0.001) and their absence (p<0.001).

4.4. Comparison of *P. notatum* and native species herbivory damages

Independetently of time, overall *batatais* cover damaged by grazing was 8.14 times greater than that of the native species (p=0.001) (Table 13).

5. Discussion

The influence of time on the *P. notatum* cover, with an average decrease of 2.2% a day, represents the seasonal effects of drought on its above ground mass. *Batatais* regression during the dry season is consistent with previous findings for tropical forages (Turner and Begg 1976, Seligman et al. 1992) and the survival of its underground parts enables posterior regrowth, making reseeding unnecessary. As is the case with other Poaceae, such desiccation can yield dry fuel that might sustain fires, limiting forest cover and benefitting grass expansion (Higgins et al. 2000, Brooks et al. 2004, Accatino et al. 2010), but the accumulated dry mass observed throughout this study was not significant.

Grazing impact on *batatais* cover was severe and when compared to control plots, plant cover was 40% smaller in the absence of deterrents and 30% smaller in their presence. These results suggest a contribution of deterrents, but no significant difference was found between treatments with and without devices. It should be noted that in the 2011-2012 interstice, the rainy season was prolonged, so that in the sampling year, there was more food available to the capybaras than usual. Such results also attest the efficacy of buried fences in excluding capybara presence; indeed, this fencing method has previously succeeded in lowering rabbit density in cropland to almost zero (Barrio 2011). Capybara size likely facilitates complete exclusion as they would need to dig deeper and larger tunnels to pass below the fences.

Sunflower cover also suffered seasonal effects, regressing 5.4% a day on average due to drought. Its insensitivity to fencing and deterrent use can be explained by capybara dietary preferences as sunflowers were not found to be consumed, but merely damaged by trampling and therefore not ripped from the ground.

Unlike *batatais* and sunflowers, native species cover did not suffer the seasonal effect, instead growing 0.5% a day on average. Such higher tolerance to drought is characteristic of woody plants (Archer 1994) as well as of some native herbaceous that dominated the native species group. Capybara impacts on native species in this site were not significant as plant cover did not differ between treatments or control, despite visible damage incidence being higher in the unfenced treatments. Such low impact is likely due to the presence of *P. notatum*, whose cover regressed 30-40% more in unfenced areas than in control plots and whose overall damage incidence was 8.14 times greater than that of native species. These results reveal a strong dietary preference by capybaras and suggest a protective effect, commending *batatais* use as a diversionary food capable of attracting and concentrating herbivore interest (Miller 2006). This preference is likely related to the leaf protein content of *batatais* (Hirata et al., 2003, Arthington et al., 2005), as its association with *Azotobacter paspali* can increment N intake while growing on the poor soils typical of degraded land (Dobereiner et al. 1972, Bodey and Chalk 1982).

Further evidence of the protective potential of *P. notatum* on other cultivated plants comes from the analysis of native species cover when cultivated alongside *batatais* or sunflowers. Soil cover by native species, throughout the duration of the experiment, was primarily represented by herbaceous, sub-shrubby and shrubby plants and was negatively correlated with both *batatais* and sunflower covers, suggesting competition with both species. However, native species cover grew 75% more quickly in association with *H. annuus* than with *P. notatum* and, from day 68 onward, it was greater alongside sunflowers. The dispersal diagram for native species cover also revealed that while it tended to expand further in sunflower plots, it stabilized over time in *batatais* plots. These results display the greater competitive potential of *P. notatum* and suggest its persistence alongside native herbaceous plants over time, which implies the maintenance of food resource for capybaras and increases the chances of woody species protection. Unfortunately, without a control of native species alone, which was logistically impossible to establish in this experiment, a conclusive and quantitative measurement of the shielding effect suggested by the results could not be obtained.

Despite the aforementioned persistence and aggressive colonization capacity, *batatais* is native to Brazil and its behavior was not invasive. Its stolons cast little shadow regressing over time and allowing the native species to eventually dominate the area. This sets *batatais* apart from invasive grasses used as forages in Brazil as a safe diversionary food. The severity of the damages such grasses can cause to neotropical ecosystems and riparian forest in particular are best exemplified by *Melinis minutiflora,* popularly known as *capim-gordura.* This African grass has been found to exclude other herbaceous species lowering local species richness (Pivello et al. 1999), inhibit the growth of riparian forest pioneers (Morosini and Klink, 1997), reduce tree and shrub recruiting in riparian strips (Hoffman et al. 2004), prevent tree regeneration in savannas (Hoffman and Haridasan 2008) and increase fire frequency and intensity by fuel loading (Hoffman et al. 2004).

Deterrents did not influence damages on the native species, which can be explained by the very low consumption of this group, but time independent analyses revealed they did mitigate damages on *batatais*, when compared to the plots without them, whereas damages were 3.27 times more prevalent in the absence of deterrents. Still, this was only a partial success, as damages were still greater in the presence of deterrents than in the control group. Trampling impacts on *H. annuus* seemed likewise partially alleviated as only the plots without deterrents suffered greater damages than the control group, although the two unfenced treatments did not differ from each other. Such mild repellent effect is in line with some previous findings as animals invariably habituate to novel stimuli (Koehler et al. 1990, Belant et al. 1996, Gilsdorf et al. 2003), but it is still greater than some previous results for small rodents (Koehler 1990, Schumake 1995, Gilsdorf et al. 2003). It should be noted that most such experiments dealing with rodents have attempted to completely exclude them from their residence areas by means of pain-inducing ultrasounds (Koehler 1990, Schumake 1995), while the present study only attempted to steer capybaras away from deterrents and ample food sources were available nearby. Habituation might be further delayed by increments to the deterrents like inclusion of visual stimuli and signal randomization (Shivik and Martin 2000). Alternatively, discomfort inducing deterrents such as pepper aerosol have proven effective (Osborn and Rasmussen 1995, Osborn 2002) and might be able to circumvent habituation altogether, but pepper spray is a problematic tool as the costs are high and its possession is legally restricted in Brazil. Unwanted impacts on neighboring wildlife must be considered, should sonic deterrents be employed near well preserved vegetation fragments, although the potency of high frequency sounds decreases sharply with distance from source. Impacts on seed dispersing fauna visiting the reclamation areas are unlikely as the deterrents would only be needed for the critical period immediately after transplantation, before the woody species could reach sexual maturity or even offer perches.

It should be noted that reforestation of native forest in Brazil requires significant financial investment reaching US$3.500,00 per ha on average, making losses to herbivory a heavy financial burden that can seriously hurt reforestation efforts. Buried fences are not just often unviable, but expensive as well, reaching US$5,00 per meter. On the other hand, the management tools explored here are comparatively cheap as *batatais* seeds can be purchased for US$1,96 the kg, whereas 18 grams suffice to seed1 m^2, and the sonic deterrents can be found for US$8,00 a unit.

6. Conclusions

P. notatum succeeded in attracting and concentrating capybara interest, showing promise as a cover crop to shield other species of interest. It is particularly attractive for use in reforestation areas as a native species that does not hamper forest reclamation, being replaced by other species over time. Overall results suggest it to be more efficient than sonic deterrents.

Sonic deterrents obtained a partial success in mitigating *P. notatum* herbivory, warranting further investigation. They should be of particular use during drought periods when alternative food sources, including *P. notatum,* where used, might be scarcer. Buried fences succeeded in preventing capybara damages altogether and their use, where technically and financially viable, is highly recommended.

The value of the management tools examined by this study is by no means limited to riparian forest reclamation efforts, but can be extrapolated to other forestry and agroforestry systems as well. In this context, sonic deterrents might be useful in situations where grass cultivation is impossible or undesirable.

7. Súmula dos resultados com referencia ao arquivo fotográfico

A nítida preferência das capivaras pela grama de batatais valida preliminarmente sua viabilidade como alimento diversionário. As mínimas perdas sofridas pelas espécies nativas quando comparadas à gramínea sugerem um efeito protetor, corroborando seu potencial defensivo.

Os resultados mistos apresentados pelos dispositivos dissuasivos recomendam seu uso em caráter complementar a outras medidas ou, em curto prazo, até que outras mediadas sejam tomadas. Recomenda-se o emprego dos dispositivos especialmente em períodos de seca em que a disponibilidade de alimento alternativos, inclusive da grama de batatais, quando empregada, pode ser reduzida.

A total eficácia do cercamento subterrâneo na exclusão de capivaras aqui atestada recomenda o emprego dessa técnica quando viável.

O potencial defensivo de ambas as estratégias de manejo aqui investigadas não se limita necessariamente a plantios de reflorestamento, podendo, em princípio, ser extrapolados para uso em cultivos agrossilvipastoris impactados por capivaras.

Arquivo fotográfico – Anexo 3

1- Grama de batatais na área experimental, à margem esquerda do rio das Velhas, Belo horizonte, MG.
2- Girassóis na área experimental, à margem esquerda do rio das Velhas, Belo horizonte, MG.
3- Herbivoria sobre grama de batatais na área experimental à margem esquerda do rio das Velhas, Belo horizonte, MG.- Herbivoria sobre grama de batatais na área experimental à margem esquerda do rio das Velhas, Belo horizonte, MG.
4- Herbivoria sobre grama de batatais na área experimental à margem esquerda do rio das Velhas, Belo horizonte, MG.- Herbivoria sobre grama de batatais na área experimental à margem esquerda do rio das Velhas, Belo horizonte, MG.
5- Registro da presença de capivaras na área experimental: fezes
6- Registro da presença de capivaras no talude que conduz à área experimental: pegadas
7- Registro da presença de capivaras no talude que conduz à área experimental: fezes

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Anexo 1 – Tabelas

Table 2 - Quasi-likelihood Regression with logarithmic link function and variance proportionate to the average function for *Paspalum notatum* cover

Model	B	Ep(β)	P-value	exp(β)
Intercept	-0.306	0.132	0.021	-
Time	-0.022	0.003	0.000	0.9784
Deterrents presente	-0.346	0.168	0.041	0.7074
Deterrents absent	-0.513	0.177	0.004	0.5986

Table 3 - Quasi-likelihood Regression with logarithmic link function and variance proportionate to the average function for *Helianthus annuus* cover

Model	B	Ep(β)	P-valor	exp(β)
Intercept	-1.716	0.218	0.000	-
Time	-0.055	0.007	0.000	0.9464
Deterrents presente	0.086	0.273	0.753	1.0897
Deterrents absent	0.363	0.257	0.158	1.4379

Table 4 - Quasi-likelihood Regression with logarithmic link function and variance proportionate to the average function for native species cover

Model	B	Ep(β)	P-valor	exp(β)
Intercept	-0.805	0.060	0.000	-
Time	0.005	0.001	0.000	1.005
Deterrents presente	-0.065	0.060	0.275	0.937
Deterrents absent	-0.080	0.060	0.186	0.924

Table 5 – Spearman correlations for native species cover alongside *Paspalum notatum* and *Helianthus annuus*

Spearman correlations	**R**	**p-value**
Native species alongside *P. notatum* x *P. notatum*	-0.29	<0.001
Native species alongside *H. annuus* x *H. annuus*	-0.33	<0.001

Table 6 – Quasi-likelihood regression with logarithmic link function and constant variance function for native species cover

Model	B	Ep(β)	P-value
Intercept	-0.995	0.077	0.000
Time	0.007	0.001	0.000
Collection alonside *P. notatum*	0.275	0.101	0.007
Time*collection alonside *P. notatum*	-0.004	0.001	0.006

Table 7 – Effect of time on *Paspalum notatum* herbivory incidence regardless of treatment as determined by the Kruskal-Wallis test N=sample size Q=quartile

Time (days)	N	Average	S.D	1st Q	2nd Q	3rd Q	P-value
3	20	0.326	0.380	0.00	0.00	0.15	
10	20	0.144	0.237	0.00	0.00	0.00	
17	18	0.216	0.348	0.00	0.00	0.00	
24	18	0.154	0.339	0.00	0.00	0.00	
31	14	0.261	0.419	0.00	0.00	0.00	0.623
40	15	0.333	0.449	0.00	0.00	0.00	
54	18	0.389	0.501	0.00	0.00	0.00	
76	12	0.125	0.312	0.00	0.00	0.00	
102	14	0.189	0.382	0.00	0.00	0.00	
117	13	0.179	0.375	0.00	0.00	0.00	

Table 8 – Ratio of *Paspalum notatum* cover damaged by herbivory A) P-values for the Wilcoxon signed rank test comparing the treatments with and without deterrents to the control and B) P-values for the Mann-whitney test comparing the two unfenced treatments to each other.

Time (days)	A) H0: mu = 0		B) H0: mu(present) = mu(abser
	Devices presente	Devices absent	
3	0.1000	0.0360	0.4641
10	0.3711	0.0579	0.0918
17	0.0975	0.1736	0.0469
24	1.0000	0.1736	0.0790
31	0.3711	0.1489	0.1065
40	0.1736	0.1489	0.1876
54	0.3458	0.0369	0.7215
76	1.0000	1.0000	1.0000
102	1.0000	0.3711	1.0000
117	0.3711	1.0000	1.0000
Overall	<0.001	<0.001	0.0005

Table 9 - Effect of time on *Helianthus annuus* trampling incidence regardless of treatment as determined by the Kruskal-Wallis test N=sample size Q=quartile

Time (days)	N	Average	S.D.	1stQ	2ndQ	3rdQ	P-value
3	13	0.054	0.133	0.000	0.000	0.000	0.518
10	15	0.311	0.457	0.000	0.000	0.000	
17	11	0.122	0.302	0.000	0.000	0.000	
24	14	0.088	0.266	0.000	0.000	0.000	

Table 10 - Ratio of *Helianthus annuus* cover damaged by trampling A) P-values for the Wilcoxon signed rank test comparing the treatments with and without deterrents to the control and B) P-values for the Mann-whitney test comparing the two unfenced treatments to each other.

Time (days)	A) H0: µranks = 0		B) H0: µranks(present) = µranks(absent)
	Deterrents presente	Deterrents absent	
0	0.3711	1.0000	0.8453
10	0.3711	0.0890	0.2972
17	1.0000	0.3711	0.5536
24	1.0000	0.3711	0.3055
Overall	0.056	0.008	0.0594

Table 11 - Effect of time on native species herbivory incidence regardless of treatment as determined by the Kruskal-Wallis test N=sample size Q=quartile

Time	N	Average	S.D.	1st Q	2nd Q	3rd Q	P-value
3	36	0.038	0.174	0	0	0	
10	39	0.018	0.069	0	0	0	
17	36	0.028	0.168	0	0	0	
24	42	0.076	0.253	0	0	0	
31	37	0.035	0.128	0	0	0	0.577
40	45	0.020	0.134	0	0	0	
54	54	0.018	0.073	0	0	0	
76	49	0.019	0.063	0	0	0	
102	54	0.023	0.081	0	0	0	
117	53	0.02	0.058	0	0	0	

Table 12 – Ratio of native species cover damaged by herbivory A) P-values for the Wilcoxon signed rank test comparing the treatments with and without deterrents to the control and B) P-values for the Mann-Whitney test comparing the two unfenced treatments to each other

Time (days)	A) H0: $\mu_{ranks} = 0$		B) H0: μ_{ranks} (present) = μ_{ranks} (absent)
	Deterrents presente	Deterrents absent	
3	0.371	1.000	0.122
10	1.000	0.100	0.045
17	1.000	1.000	0.194
24	0.173	1.000	0.285
31	0.173	1.000	0.331
40	1.000	1.000	0.335
54	0.173	1.000	0.335
76	0.181	0.181	1.000
102	0.371	0.100	0.317
117	0.173	0.059	0.271
Overall	<0.001	<0.001	0.837

Table 13 – Mann-Whitney test for time independent overall damage ratios for *Paspalum notatum* and native species

Plant species	N	Average	S.D	1st Q	2nd Q	3rd Q	P-value
P. notatum	162	0.236	0.379	0.000	0.000	0.500	<0.001
Native species	445	0.029	0.129	0.000	0.000	0.000	

Anexo 2 – Croqui de plantio das espécies lenhosas na área experimental

E E E	E E E	33	6	19	EEE
6	7	10	1	20	EEE
14	21	17	14	2	EEE
6	5	3	6	33	EEE
19	6	34	7	24	EEE
43	3	18	20	32	EEE
34	18	15	23	50	EEE
10	6	12	40	8	EEE
44	41	22	43	19	EEE
21	17	3	48	20	EEE
3	5	34	20	2	EEE
21	24	37	30	12	EEE
34	43	14	44	21	EEE
22	21	18	14	24	EEE
14	12	49	9	8	EEE
18	34	31	19	7	EEE
46	15	34	23	19	EEE
18	21	15	32	17	EEE
36	15	36	9	2	EEE

1 *Luehea divaricata*
2 *Luehea grandiflora*
3 *Malpighia glabra*
4 *Persea americana*
5 *Eriobothrya japonica*
6 *Morus nigra*
7 *Anadenthera colubrina*
8 *Centrolobium tomentosum*
9 *Lithraea molleoides*
10 *Myrocarpus frondosus*
11 *Dypterix alata*
12 *Capsella bursa-pastoris*
13 *Protium heptaphyllum*
14 *Ocotea puberula*
15 *Trichilia apiana*
16 *Cecropia sp.*
17 *Erythrina falcata*
18 *Albizia hasslerii*
19 *Cassia occidentalis*
20 *Psidium guajava*
21 *Psidium guianeense*
22 *Astronium fraxinifolium*
23 *Schizolobium parahyba*
24 *Inga ingoides*
25 *Tabebuia chrysotricha*
26 *Jacaranda cuspidifolia*
27 *Hymenaea courbaril*
28 *Cariniana estrellensis*
29 *Acrocomia aculeata*
30 *Acrocomia intumescens*
31 *Macherium sp.*
32 *Coussapoa microcarpa*
33 *Miconia cinnamomifolia*
34 *Mimosa bimucronata*
35 *Swietenia macrophylla*
36 *Myrtus communis*
37 *Ceiba speciosa*
38 *Caesalpinia echinata*
39 *Copaifera langsdorfii*
40 *Piptadenia gonoacantha*
41 *Platycyamus regnellii*
42 *Pterigota brasiliensis*
43 *Eugenia uniflora*
44 *Rapanea guyanensis*
45 *Punica granatum*
46 *Mimosa caesalpineafolia*
47 *Croton urucurana*
48 *Samanea tubulosa*
49 *Enterolobium contortisiliquum*
50 *Tamarindus indica*
51 *Tibouchina granulosa*
52 *Bixa orellana*
53 *Eugenia pyriformis*
EEE Talude

Anexo 3 – Arquivo Fotográfico

1 **- Grama de batatais na área experimental, à margem esquerda do rio das Velhas, Belo horizonte, MG.**

2 **- Girassóis na área experimental, à margem esquerda do rio das Velhas, Belo horizonte, MG.**

3 **- Herbivoria sobre grama de batatais na área experimental à margem esquerda do rio das Velhas, Belo horizonte, MG.**

4 **- Herbivoria sobre grama de batatais na área experimental à margem esquerda do rio das Velhas, Belo horizonte, MG.**


5 - Registro da presença de capivaras na área experimental: fezes


6 - Registro da presença de capivaras no talude que conduz à área experimental: pegadas

7 - Registro da presença de capivaras no talude que conduz à área experimental: fezes